specification and the claims as follows:

In the Specification:

On page 1 after the title and before line 4, insert the following new paragraphs and headings as follows:

Applicant claims, under 35 U.S.C. §§ 120 and 365, the benefit of priority of the filing date of September 21, 2000 of a Patent Cooperation Treaty patent application, copy attached, Serial Number PCT/EP00/09232, filed on the aforementioned date, the entire contents of which are incorporated herein by reference, wherein Patent Cooperation Treaty patent application Serial Number PCT/EP00/09232 was not published under PCT Article 21(2) in English.

Applicant claims, under 35 U.S.C. § 119, the benefit of priority of the filing date of September 24, 1999 of a German patent application, copy attached, Serial Number 199 45 748.4, filed on the aforementioned date, the entire contents of which are incorporated herein by reference.

Background of the Invention

Field of the Invention

Replace the paragraph beginning on page 1, line 4 with the following paragraph:

The present invention relates to a method for determining at least one time constant of a reference model in a cascaded controlling arrangement.

Replace the paragraph beginning at page 1, line 7 with the following heading and paragraph:

Description of the Related Art

Usually a cascaded controlling structure, including a position, rpm and current control device, is employed in numerically controlled machine tools. As a rule, the speed control device, which is connected downstream of the position control device, is embodied as a PI speed control device and includes a proportional branch (P) and an integral branch (I). The phase response of the upstream connected position control device worsens as a result of the effect of the integral branch of the speed control device. It is therefore necessary as a consequence of this to reduce the loop gain kV of the position control device a priori in order to prevent oscillations in the drive systems of the machine tool controlled by the controlling device. However, as large as possible a loop gain kV of the position control device is desired in principle.

Replace the paragraph beginning at page 1, line 29 with the following heading and paragraph:

SUMMARY AND OBJECTS OF THE INVENTION

It is therefore an object of the present invention to disclose a method for determining at least one time constant of a 2nd order reference model, which is arranged in a cascaded controlling device of a machine between a position control device and an speed control device, and which assures an optimized control behavior of the controlling device.

Replace the paragraph beginning on page 1, line 33 with the following paragraph:

This object is attained by a method for determining at least one time constant of a reference model, which is designed as a 2nd order time-delay element of a

machine. The method includes detecting an oscillation frequency of an undamped machine oscillation and determining an optimized value of a time constant of the reference model as a function of the detected oscillation frequency of the undamped machine oscillation.

Delete the paragraph beginning at page 1, line 35.

Replace the paragraph beginning on page 1, line 37 with the following paragraph:

The parameterization of a suitable 2nd order reference model for the most varied types of machines is now possible by the method of the present invention. Here, the resulting reference model essentially always assures that at least the undesired influence of the integral portion of the speed control device on the control behavior is eliminated.

Between lines 2 and 3 of page 2, insert the following new paragraph:

It should be noted that the machine tools controlled in the past and by the present invention can generally thought of as falling with one of two categories. One category or type of machine tool regards rigid machines that are not too large in structural size, which is mostly directly driven or has linear motors. A second category or type of machine tool regards machine tools with a dominant natural frequency in the range between 15 Hz to 80 Hz, in which no sufficiently large kV factor can be set.

Replace the paragraph beginning on page 2, line 3 with the following paragraph:

Depending on the machine type, one time constant or two time constants are

determined in accordance with the present invention, which determine the behavior of the reference model and therefore affect the control behavior of the controlling arrangement during the actual controlling operation. However, in accordance with the present invention at least the so-called second time constant of the reference model is basically determined as a function of a detected oscillation frequency of a continuous machine oscillation.

Replace the paragraph beginning on page 2, line 9 with the following paragraph:

Surprisingly, or contrary to theoretical reflections, it is now possible by the steps of the present invention for determining the time constant to also compensate controlled systems with idle times and delay elements for machines which theoretically would require higher order reference models; this applies in particular to the above mentioned category of non-rigid machines with dominant natural frequency. The determination of theoretically exact nth-order reference models ($n > 2$) in such machines would be connected with a very large outlay. In contrast to this it is possible by the use of second order time-delay elements as the reference model, whose time constants are determined in accordance with the present invention, to keep the resulting outlay for parameterization of the reference model low.

Replace the paragraph beginning on page 2, line 18 with the following paragraph:

The method in accordance with the present invention can be performed manually, as well as in an automated manner.

Replace the paragraph beginning at page 2, line 20, with the following

paragraph:

Further advantages, as well as details of the method in accordance with the present invention ensue from the subsequent description of exemplary embodiments by the attached drawings.

Replace the paragraph beginning at page 2, line 23, with the following paragraph:

Shown here are in:

Replace the paragraph beginning on page 2, line 24 with the following heading and paragraph:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a block diagram representation of a part of an embodiment of a cascaded controlling structure of a numerically controlled machine tool in accordance with the present invention;

Replace the paragraph beginning at page 2, line 26 with the following paragraph:

FIGS. 2a and 2b show a flow diagram in each for explaining an embodiment of a method of the determination, in accordance with the present invention, of the time constant of a 2nd order reference model to be used with the cascaded controlling structure of FIG. 1;

Replace the paragraph beginning at page 2, line 28 with the following paragraph:

FIGS. 3 to 21, respectively, show different representations to be used with the cascaded controlling structure of FIG. 1, which will be explained in greater detail in

the ANNEX.

Before lines 29 and 30 at page 2, insert the following heading:

DESCRIPTION OF THE PREFERRED EMBODIMENT(S) OF THE INVENTION

Replace the paragraph beginning at page 2, line 33 with the following paragraph:

The portion of the controlling structure represented includes a position control device 10, as well as a downstream- connected speed control device 20. The actual controlled system 30 is arranged downstream of the speed control device 20 and is only schematically indicated. In the present example, the speed control device is embodied as a PI control device (proportional-integral control device); the integral branch 21, as well as the proportional branch 22 of the speed control device 20 are represented separately of each other in FIG. 1. A reference model 40 is arranged between the position control device 10 and the speed control device and is embodied as a 2nd order time-delay element, i.e. a so-called PT2 element. The reference model 40 simulates the behavior of the closed speed control device 20 without an integral portion and in this way assures that at least the undesired influence of the integral portion, or integral branch 21, on the control behavior of the speed control device is eliminated. As already indicated above, by the steps to be explained in what follows it is possible in a surprising manner to also parameterize reference models which compensate controlled systems with idle times and delay elements. In theory it would be necessary to parameterize reference models with orders $n > 2$ for such controlled systems, which would be relatively expensive.

Replace the paragraph beginning at page 3, line 20 with the following

paragraph:

Contrary to theoretical considerations it is shown by the present invention that the use of 2nd order reference models, whose time constants T1 and T2 are determined in accordance with the present invention, is even possible when the respective system would actually have to be simulated by a reference model of higher order n, i.e. $n > 2$. However, the mathematically exact representation of such a complex system by an appropriate nth order reference model would basically cause an extremely high computational effort. In actuality this has the result that by the use of a 2nd order reference model, whose time constants T1 and T2 are determined by means of the invention, it is possible to also optimize the control behavior of the speed control device 20 for machines which are part of the second category already discussed above. Here, by employing a 2nd order reference model, which is parameterized in accordance with the present invention, in these systems, not only is the influence of the integral branch of the speed control device eliminated, but moreover the influence of additional delays, or idle times, in the controlled system is also minimized. It is surprisingly possible to use loop gains kV in such systems with 2nd order reference models parameterized in accordance with the present invention, which are greater than possible loop gains kV in case of a non-existing, or switched off integral branch in the speed control device.

Replace the paragraph beginning at page 3, line 36 with the following paragraph:

The operation in accordance with the present invention for determining the time constants T1, T2 for the 2nd order reference model will now be explained by the

flow diagrams in FIGS. 2a and 2b.

Replace the paragraph beginning at page 6, line 35 with the following paragraph:

The theoretical considerations on which the present invention is based will be explained in greater detail in what follows in the following ANNEX and several simulations and test results will be presented.

Replace the paragraph beginning at page 7, line 11 with the following paragraph:

The method of the present invention and the arrangement of the present invention were tested by a mathematical simulation. This simulation which, besides the mathematical machine model, also contains the mathematical model of the present invention, will be described in what follows.

Replace the paragraph beginning at page 7, line 15 with the following paragraph:

The mass inertia moment of the controlled system, together with the momentary constants of the motor, are the defining characteristics of the system. The following parameters are used in connection with this:

Mass inertia $J_L = 50$ kgcm^2

Motor constant $k_{MC} = (1.5/\ 2) * (Nm/A_{eff})$, wherein A_{eff} is known in the art to represent an effective motor current which is measured in Amperes

Therefore, the controlled system G(s) is determined by:

$G(s) = (num/den) = 1/(J_L * s)$.

Replace the paragraph beginning at page 7, line 31 with the following

paragraph:

The conversion from the radian frequency ω to U/s (U represents the number of rotations) takes place by a downstream-connected P-element with $1/(2 * \pi)$. A disturbance can be introduced via the input "momentary disturbance Ms", which simultaneously affects the momentary value and the actual rpm. This is intended to correspond to a typical disturbance because of a milling cutter action and is used to rate the disturbance rigidity.

Replace the paragraph beginning at page 7, line 36 with the following paragraph:

For simulating realistic rpm-connected losses, a derivative feedback k'p of the internal system output to the momentary summing point takes place. By this a new controlled system G'(s) is created:

$$G'(s) = (1/(J_L * s))/(1 + k'_p /(J_L * s)))$$

$$G'(s) = (1/(k'_p + (J_L * s))$$

$$G'(s) = 1/k'_p * 1/(1 + (J_L/k'_p * s))$$

Replace the paragraph beginning at page 8, line 4 with the following paragraph:

A TP1 control device is created by this derivative feedback.

Replace the paragraph beginning at page 8, line 5 with the following paragraph:

A model of the 1st order controlled system with disturbance introduction is represented in FIG. 3. As shown in FIG. 3, a signal lq is fed to an amplifier 300 that multiplies the signal lq by a momentary constant to generate a signal 302 that is fed to

adder 304. A momentary disturbance signal Ms is fed to the adder 304. As shown in FIG. 3, the adder 304 is connected to a control system 306 that generates the signal G(s) = (num/den) which is fed to a component 308 that generates a loss signal 310 that is a function of rpm. The loss signal 310 is fed back to the adder 304. The signal G(s) and the signal Ms are each fed to a second adder 312 that adds the two signals to generate signal 314. The signal 314 is then fed to an amplifier 316 to generate signal Msl.

Between lines 12 and 13 at page 8, insert the following paragraph:

As shown in FIG. 4, the signal lq is fed to a control system 400 with controlled disturbance that is supplied by a momentary disturbance device 402. The control system generates a resultant signal nsi.

Between lines 22 and 24 at page 8, insert the following paragraphs:

As shown in FIG. 5, a jerk signal 500 is fed to a switch 502 along with an rpm jerk signal 504 and a feedback signal 506. The switch 502 sends one of the three signals 500, 504, 506 to an amplifier 508 where the signal is multiplied to generate a resultant signal 510. The resultant signal 510 is sent to an adder 512, a reference model component 514 and a second switch 516. At the reference model component 514, the resultant signal 510 is operated by the factor (2)/MP2500 and the signal 518 is fed to the switch 516. The switch 516 selects one of the signals 518, 510 and a reference model signal 520. The selected signal is sent to an adder 522 that adds the selected signal with a disturbance signal 524. The combined signal 526 is fed to component 528 that applies the factor MP2510/s to generate signal 530 that is fed to adder 532 and multiplexer 534.

At the adder 512, the resultant signal 510 is added to the disturbance signal 524 to generate a signal 536 that is fed to amplifier 538 that multiplies the signal 536 by a factor that results in signal 540 that is later fed to adder 532 and multiplexer 534. The adder 532 generates a signal 541 that is fed to control system 542 that adjusts the signal 541 to take into account disturbance effects. The signal 524 output from the control system 542 is fed back to both adder 512 and adder 522. The signal 524 is also fed to an amplifier 546 that generates a signal 548 that is fed to multiplexer 550 and component 552 that applies the factor 1/s. The signal 554 generated by component 552 is fed to amplifier 556 and the amplified signal 558 is fed to adder 560.

A pulse generator 562 generates a signal that is operated by a point set point component 564 that applies a factor 1/s to generate signal 566. The signal 566 is fed to both adder 560, adder 568 and multiplexer 570. The adder 568 adds the signals 558 and 566 to generate signal 572 that is multiplied in amplifier 574 and the signal 576 is fed to multiplexer 550. The adder 560 adds signals 558 and 566 to generate a signal that is amplified by amplifier 577 to generate feedback signal 506.

The multiplexer 570 generates a signal 578 that is fed to amplifier 580 and the signal 582 is fed to multiplexer 550. The multiplexer 550 sends its signal to a multiplexer 584 that also receives a signal from multiplexer 534. The multiplexer 584 generates a signal 586 that is received by component 588 that is a MATLAB data file where all resulting simulation data results are stored and from which all graphs shown in FIGS. 6-12, 14-17 and 20 are extracted.

Between lines 33 and 34 at page 8, insert the following new paragraph:

Once the skip size is set to 200 mm/min the kinematics and current flow of the system are represented by the graphs of FIG. 6. In particular, the top graph represents the position (mm) /velocity (mm/s) of the system as a function of time (s). The curve sactual represents the actual position, snominal the nominal position, sdiff is snominal – sactual and vactual is the actual velocity. The lower graph maps the various currents (A) of the system versus time (s). The curve l(ki) represents the current of the integral branch motor current, the curve l(kp) represents the proportional branch motor current and lq = l(ki) + l(kp). Similar graphs are presented in FIGS. 7-10, 14-17 and 20. One difference in the graphs is that the graphs of FIGS. 14-17 and 20 is that the time scale is in minutes.

Replace the paragraph beginning at page 10, line 14 with the following paragraph:

Position control device amplification MP1510 [m/min/mm] = 15 P-factor (speed control device) MP2500 [As] = 9 I-factor (speed control device) MP2510 [A] = 2200, wherein A represents Amperes.

Replace the paragraph beginning at page 10, line 30 with the following paragraph:

The following physical values appear in this closes control loop:

P-factor speed control device: in [As/U]
Motor constant: kMC/sqrt(2) in [Nm/A]
Moment of mass inertia of the system $\underline{J}_L$

Thus, the conversion function G(s) of the open control loop is:

$$G(s) = MP2500 * k_{MC} * 1/(2 * \pi) * 1/(J_L * s)$$

$k'_p = MP2500 * k_{MC} * 1/(2 * \pi)$

$G(s) = k'_p * 1/([J_I] J_L * s)$

The conversion function H(s) of the closed control loop is:

$H(s) = G(s)/(1 + G(s))$

$H(s) = (k'_p /(J_L * s))/(1 + (k'_p/(J_L] * s)))$

$H(s) = 1/(1 + (J_L * s)/k_p')$

$H(s) = 1/(1 + T_1 *s)$

A PT1 element with the time constant T1 is obtained as the IPC reference model:

$T_1 = J_L/k_p' = (J_L*2 * \pi) /(MP2500 * k_{MC})$ (F1)

Replace the paragraph beginning at page 11, line 31 with the following paragraph:

Heidenhain controls have an acceleration feedforward control, which can be set by a machine parameter. This machine parameter MP26 provides the reciprocal value of the angular acceleration α per current in [As^2/U]. The time constant of the IPC can be calculated in a simple manner by the angular acceleration.

Mel = Electrical moment [Nm]
kMC = Momentary motor constant [Nm/A]
J_L = Moment of mass inertia [kgm^2]
MP26 = Acceleration feedforward control [As^2/U]

$M_{el} = I_{MOT} * k_{MC}$

$\alpha = M_{el}/J_L$

$\alpha = (I_{MOT} * 2 * \pi)/MP26$

This is equal to:

$J_L / k_{MC} = (MP26)/2 * \pi$

This inserted in (F1):

$T_1 = J_L/k_p' = (J_L*2 * \pi) /(MP25 * k_{MC})$

$T_1 = MP26/MP25$ (F2).

Between lines 33 and 35 at page 12, insert the following new paragraph:

Please note that the graphs shown in FIGS. 11 and 12 are known as Bode diagrams which are used to characterize the behavior of a filter. In particular, the upper graphs of FIGS. 11 and 12 show the amplitude/gain response of the filter. The lower graphs show the phase response of the filter. The x-axis represents the frequency over a certain range.

Between lines 16 and 18 at page 13, insert the following new paragraphs:

As shown in FIG. 13, a jerk signal 600 is fed to a switch 602 along with a speed feedforward control signal 604 and an rpm jerk signal 606. The switch 602 sends one of the three signals to an amplifier 608, which applies MP2020 to generate a signal 610 that is fed to the speed control system 612.

The speed control system 612 receives five other signals. One of the signals 614 is generated by the IPC component 616 and another of the signals is the jerk signal 600. The two other signals 622, 624 are initiated by interpolator 626 where the a_soll and w_soll signals from the interpolator are amplified by amplifiers 628, 630, respectively, that apply MO2020 to generate the resultant signals received by the control system 612.

The control system 612 generates a signal 632 that is received by a control system with disturbance introduction 634 whose output signal 636 is fed back to the control system 612 and a component 638 that applies 1/s to the signal which results in signal 640. Signal 640 is fed to an amplifier 642 that applies MP2020 to generate a signal 644 that is received by adder 646 that also receives a signal s_soll. The adder 644 combines the two signals to provide a signal 648 that is amplified via amplifier 649 and received by adder 650. The adder 650 sums the signal from amplifier 649 with a signal 652 that is the result of the amplification, via amplifier 654, of signal a_soll generated by the interpolator 626. The speed.control signal 604 is then fed back to the switch 602.

As shown in FIG. 13, the signal s_soll is also fed to an amplifier 656 that sends the amplified signal to an adder 658 and a multiplexer 660. The adder 658 receives a signal 662 that is the result of the amplification of signal 644 via amplifier 664. The signal 662 is also sent to multiplexer 660. The multiplexer 660 and the adder 658, in combination with amplifier 666, send signals 668, 670 to a multiplexer 672. The multiplexer 672 also receives a signal 674 from an amplifier 676 that amplifies signal 636.

The multiplexer 672 generates a signal 678 that is fed to multiplexer 680. The multiplexer 676 also receives a signal 682 from the controller 612. The multiplexer 680 generates a signal 684 that is received by component 686 that is a MATLAB data file where all resulting simulation data results are stored and from which all graphs shown in FIGS. 6-12, 14-17 and 20 are extracted

Replace the paragraph beginning at page 13, line 20 with the following

paragraph:

In what follows, the various feedforward controls are sequentially switched in. To compare the effects, all simulation parameters were kept constant.

System Parameters:

Momentary constant Ktc[Nm/A] = 1.5 * sqrt(2)

Momentary load inertia $J_L[kgm^2]$ = 9

Rpm losses Nm/ω = 0.15

Control device circuit parameters:

Position control device amplification MP1510 m/min/mm = 9

P-factor (speed control device) MP2500 [As] = 9

I-factor (speed control device) MP2510 [A] = 2200

Interpolation parameters:

Jerk $r\ [m/s^3]$ $= 2 * 10^3$

Acceleration $a\ [m/s^2]$ = 5

Speed v [m/s] = 0.4 / 60

Position s [m] $= 4 * 10^{-4}$.

Replace the paragraph beginning at page 14, line 7 with the following paragraph:

The resulting following error without feedforward controls is represented in FIG. 14. A maximum following error of approximately 45 μm results, which is impermissibly high.

Replace the paragraph beginning at page 14, line 12 with the following paragraph:

The resulting following error without feedforward controls is represented in FIG. 15. A maximum following error during the acceleration phase of 10 μm results.

Between lines 35 and 36 at page 14, insert the following new paragraphs:

As shown in FIG. 18, a resultant signal 700 is formed as the combination of the product of signals a_soll and T_1 being added to the signal n_soll. The resultant signal 700 is fed to the IPC 702 which generates a signal 704 that is added with the signal n_ist so as to form a signal 706. The signal 706 is then fed to an integral branch 708.

Replace the paragraph beginning at page 15, line 3 with the following paragraph:

The IPC with acceleration and jerk control is represented in FIG. 19. As shown in FIG. 19, a resultant signal 800 is formed as the combination of the signals r_soll, Tr, a_soll, T_1 and n_soll so that resultant signal 800 is fed to the IPC 802 which generates a signal 804 that is added with the signal n_ist so as to form a signal 806. The signal 806 is then fed to an integral branch 808 which in turn generates an output signal 810. The proportional branch 812 receives a signal 814 so as to generate an output signal 816 that is added with the output signal 810.

Replace the paragraph beginning at page 15, line 15 with the following paragraphs:

The structure of the speed control device block with feedforward control in the control device output is represented in FIG. 21. In particular, the structure includes six input signals 900, 902, 904, 906, 908, 910. The input signal 900 is fed to a switch 912. The input signal 906 is fed to an amplifier 914 where the amplified signal 916 is

fed to an IPC model feedforward control 918 that applies the factor 1/MP2500. The resultant signal 920 is fed to switch 912. The switch 912 also receives a constant signal 922.

The signal 908 is fed to the IPC phase reference model control 924 that also applies the factor 1/MP2500 so as to generate signal 926 that is fed to switch 928. The switch 928 also receives signal 908 and signal 930. The switch 928 chooses one of the three signals 908, 926 and 930 and feeds them to an adder 932 that also receives signal 910. The added signal 934 is sent to a component 936 that applies the factor P2510/2*s so as to generate signal 938.

As shown in FIG. 21, the signal from the switch 912 and the signals 902 and 922 are sent to a switch 940 that sends one of the three signals to both adder 942 and adder 944. The adder 942 receives the signal from switch 940 and signal 938 and adds the two to generate signal 944 which is sent to multiplexer 946. The multiplexer 946 also receives signals 956 and 965 and sends a signal 966 to an output.

Signals 902, 922 and 948, which is the result of the amplification of signal 904 by amplifier 950 are sent to switch 952 where one of the three is sent to adder 944. The adder 944 receives two other signals 954 and 956. Signal 954 is the result of amplifying signal 910 by amplifier 958. Similarly, signal 956 is the result of amplifying signal 960 via amplifier 962. Signal 956 is the result of adding signals 908 and 910 by adder 964. As shown in FIG. 21, the signals from the switches 940, 952 and signals 938, 954 and 956 are combined by adder 944 to generate signal 965 that is sent to an output.

After line 15 at page 19 insert the following new paragraph: